RATE OF OVIPOSITION BY *CULEX QUINQUEFASCIATUS* IN SAN ANTONIO, TEXAS, DURING THREE YEARS[1]

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ABSTRACT. Two artificial oviposition sites containing aged alfalfa pellet infusion were exposed to natural populations of *Culex quinquefasciatus* in San Antonio, Texas, for 3 years. Numbers of egg rafts were counted daily and compared to weather data from a nearby station. Egg rafts were generally most numerous in summer months, declining in fall and increasing in spring. Oviposition occurred in winter only when temperatures were high enough. A particularly severe winter in 1983–84 reduced winter activity, but was followed by a great increase in oviposition in late spring. In summer, increases of oviposition were correlated with rainfall 2 to 3 weeks before the time of oviposition. Rainfall at the time of oviposition appeared to decrease oviposition. On a seasonal basis, lack of rainfall in the summer of 1984 was correlated with a decrease in oviposition.

INTRODUCTION

The wide distribution of *Culex quinquefasciatus* Say in both the northern and southern hemispheres exposes this species to a variety of climatic challenges to its survival. It is able to adjust its seasonal cycle of reproductive activity to environments ranging from temperate continental climates to humid tropics. Examples of the flexibility include reports of peak reproduction in the warmest season in subtropical or temperate continental climates (Brogdon (Tennessee) 1984, Carlson (Florida) 1982, Hunt and Hacker (Texas) 1984, Villavaso and Steelman (Louisiana) 1970), in the coolest season in deserts (Walters and Smith (California) 1980), in the coolest season in a settling lagoon (O'Meara and Evans (Florida) 1982), and in the dry season (de Meillon et al. (Burma) 1967) or the wet season (Barrera et al. (Venezuela) 1979) in the humid tropics.

Most of the studies of seasonal distribution of *Cx. quinquefasciatus* treat only a single year of observations. These studies have been adequate to establish broad seasonal influences and immediate effects of weather where the effect is repeated often enough to produce convincing replication in one year. The study discussed in this paper reports the results of 3 consecutive years of observations. Because of the length of the study, results reflected the effects of differences in severity of seasons and the influence of unusual weather events.

MATERIALS AND METHODS

Methods for collection of egg rafts were identical to those described in a preliminary paper covering the first 14 months of the study (Strickman 1983). Briefly, 2 foul-water oviposition traps were placed in shady locations protected from direct rainfall 25 m apart in the yard of a residence in southeastern San Antonio, Texas. Each trap consisted of a 6-liter plastic trash can containing foul water (32 g of alfalfa pellets in 4 liters of water aged 11 days at 27 ± 2°C in an environmental chamber, based on the method of Lewis et al. (1974)). Egg rafts were removed daily, with a sample of no more than 5 rafts per day hatched for species determination. Traps were exchanged every 7 days with traps containing freshly aged foul water. The period of sampling reported here extended from September 30, 1981, to November 12, 1984. Weather data were taken from the official records at Kelly Air Force Base, San Antonio, located 15 km from the study site.

Graphical analysis was chosen as the main tool for interpretation of the data. Following extensive trials of linear regression, cosin curve fitting (example in Hayes and Downs 1980), and Box-Jenkins methodology (examples in Hacker et al. 1973a, 1973b), it was found that, for this study, these techniques provided few insights into the biology of the species that were not reflected in the graphs. Quantitative modeling might result from such analyses, but a model based on 2 traps probably would not be of practical use.

The quantities displayed on the graphs were smoothed by taking 7-day moving averages (Downing 1976). This process consisted of calculating a given day's quantity as the mean of that day combined with that from the previous 6 days. The result was to decrease the apparent variation in the data, making trends easier to see. Because results for the 2 traps followed similar patterns, the sum of rafts in the traps was used as the unit of daily oviposition. Daily minimum temperature was chosen over maximum temperature because of the former's closer correspondence to shaded water and nighttime temperatures.

[1] Opinions and assertions contained herein are the private views of the authors and are not to be construed as official, nor as reflecting the views of the supporting agencies.

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Multiple autoregressive integrated moving average (MARIMA, a form of Box-Jenkins methodology, Makridakis et al. 1983) analysis was completed to supplement interpretation of the relationships between rainfall and oviposition during summer months (June 1–September 30). The BMDP statistical software (BMDP Statistical Software, Inc., Los Angeles, CA; program version April 1985 (VAX/VMS)) was used to produce analyses similar to those reported by Hacker et al. (1973a). Each summer's data (number of egg rafts transformed by adding one and taking the natural logarithm) was treated by first estimating an autoregressive integrated moving average model for rainfall with one order of autoregression and zero orders of integration and moving average (ARIMA (1,0,0)). This model was chosen initially because rainfall appeared to have no trend requiring integration and no obvious requirement for a moving average component (i.e., no regular periodicity). This ARIMA model was modified until there was no significant autocorrelation of the residuals for 30 days of lag, that is, until the difference between the model and the data showed no significant pattern of correlation within the series. The model of rainfall and the oviposition data were then used as input to produce measures of autocovariance between residuals of rainfall and oviposition. These results are presented as a graph of autocovariance of rainfall from 30 days before to one day after the day of oviposition.

RESULTS AND DISCUSSION

During the entire study, 7,937 egg rafts of *Cx. quinquefasciatus* were collected during 1,134 nights. Figure 1 presents data for 3 complete calendar years beginning October 6, 1981, and ending October 5, 1984. One of the most evident trends in the data was seasonality. In all 3 years, oviposition decreased in the fall, continued at minimal levels in the winter, then rose in the spring to the peak levels of summer.

Temperature was closely correlated to the level of oviposition. Not only did oviposition follow the seasonal trends of temperature, but also the shorter scale increases and decreases in temperature. This correspondence was particularly evident in 1981–82 when each period of increased temperature from December through April was correlated with an increase in oviposition. Table 1 presents a summary of oviposition in relation to temperature. Oviposition virtually ceased when minimum temperature dropped below 2°C and did not reach a mean of one egg raft per day in 2 traps until minimum temperature exceeded 8°C. Greatest oviposition was observed when minimum temperatures rose above 22°C.

In one case, at least, the effect of temperature apparently reached far beyond its immediate impact on oviposition. The winter of 1983–84 presented the challenge of unusually prolonged and severe freezing temperatures (December 18–31) with a lowest minimum temperature of −10.6°C on December 25 (a record for the date). Oviposition following this period nearly ceased until April (one egg raft deposited on each of the following dates: January 30, February 10, March 18, and March 25), in contrast to the 2 previous years when winter oviposition occurred during brief warm periods. Also, oviposition increased in May and June, 1984, to levels greater than previously observed. The cold in December, 1983, probably reduced the population of *Cx. quinquefasciatus* below its normal winter levels so that the population was not able to take advantage of brief warm periods later in the winter. In spring and early summer, the population increased rapidly, possibly because it was released from competitors, predators, and parasites that had also succumbed to the severe winter and which could not recover as quickly as *Cx. quinquefasciatus*.

Correlations between rainfall records and rate of oviposition were noted in the data, despite the distance between the weather station and the study site. Possibly, the location of both areas on the same side of town subjected them to the same weather patterns. Association between rainfall and oviposition was apparently of 3 types. First, heavy rain corresponded to days when oviposition was temporarily reduced. On the 7 days during the entire study when rainfall exceeded 20 mm in a 24-hr period and ovipositing females were active (greater than 10 rafts in both traps during the 2 days preceding rain), the number of egg rafts deposited was reduced by half (S.D. = 0.3). Second, prolonged lack of precipitation could have reduced the number of larval sites and, consequently, the population of ovipositing females. This may have occurred during the summer of 1984 when a reduction in oviposition from June through September corresponded to scarce rainfall. Finally, the number of egg rafts increased in the traps approximately 2 weeks after periods of rainfall and concomitant small dips in temperature during the summer (Fig. 2). This correspondence appeared to be the explanation for at least part of the variation in number of egg rafts observed in the summer. From the data available, it is not possible to determine whether this effect was the result of an increased population of ovipositing females or the result of a gradual decrease in number of natural sites competing with the traps.

The patterns of autocovariance between rainfall and oviposition in the summer (Fig. 3) reflect the relationships discussed above. First,

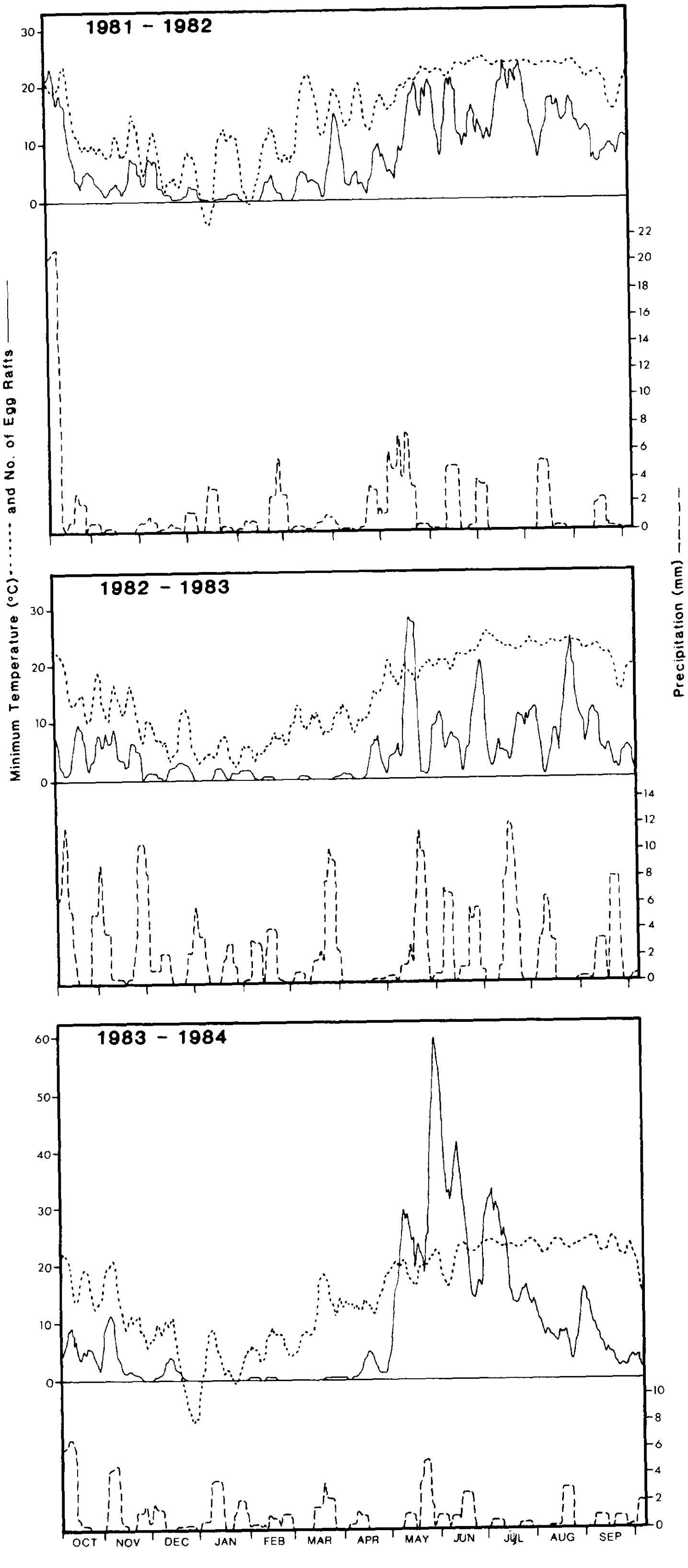

Fig. 1. Seven-day moving averages of daily precipitation, temperature, and oviposition by *Culex quinquefasciatus* in 2 foul-water oviposition traps. October 6, 1981–October 5, 1984, San Antonio, Texas.

Table 1. Daily oviposition by *Culex quinquefasciatus* in 2 foul-water oviposition traps in relation to minimum air temperature. Intervals are from lower number to just below higher number. San Antonio, Texas, September 1981–November 1984

Interval of minimum temperature (°C)	N	Egg rafts			
		Mean	SD	Minimum	Maximum
−12 to −10	1	0	0	0	0
−10 to −8	3	0	0	0	0
−8 to −6	6	0	0	0	0
−6 to −4	5	0.2	0.4	0	1
−4 to −2	15	0	0	0	0
−2 to 0	9	0	0	0	0
0 to 2	37	0.3	0.9	0	5
2 to 4	57	0.8	2.2	0	13
4 to 6	56	0.4	1.1	0	5
6 to 8	76	0.9	1.8	0	8
8 to 10	52	1.7	3.9	0	19
10 to 12	79	2.2	4.4	0	33
12 to 14	72	3.9	7.2	0	40
14 to 16	59	4.8	7.2	0	42
16 to 18	64	7.4	8.6	0	33
18 to 20	80	9.2	14.0	0	71
20 to 22	127	9.1	12.4	0	92
22 to 24	235	13.4	12.5	0	58
24 to 26	90	14.4	11.2	0	54
26 to 28	11	14.1	12.2	0	32

autocovariance was generally negative in 1984 when oviposition was trending downward. This pattern did not indicate that rainfall reduced oviposition; instead, it indicated that the negative trend concealed relationships with rainfall that were visible in Fig. 2. The autocovariance graphs for 1982 and 1983 suggest that rainfall and oviposition were positively correlated 2 to 3 weeks after the rain and negatively correlated at the time of rainfall. The broad period of positive correlation is not surprising, considering the approximate nature of the correspondence between peaks of rainfall and oviposition in Fig. 2.

This study offered some new details to the general picture of seasonal distribution of *Cx. quinquefasciatus*. Numerous authors (as cited above) have documented the summer abundance and winter scarcity of the species in middle latitudes based on single years of data. The pattern of a particularly severe winter followed by unusually large populations in early summer was only apparent in this study because 2 other years were available for comparison.

The influence of a number of specific weather events have been treated previously in the literature. Hayes (1975), Hayes and Hsi (1975), Smittle et al. (1975), and Strickman (1983) commented on the ability of the species to cease oviposition during cold periods and resume oviposition when temperatures increased. Hayes and Hsi (1975) found no relationship between rainfall and oviposition during a single year in Texas; whereas, de Meillon et al. (1967) reported increases in Burmese storm drains in the dry season and Barrera et al. (1979) reported increases in Venezuelan cemetary urns in the wet season. The data from the current study indicated that rainfall has a number of effects, including interruption of oviposition, maintenance of populations, and variation in oviposition observed in traps during summer.

Results of this study suggest that populations of *Cx. quinquefasciatus* in dry subtropical areas vary from year to year and during summer. From a practical standpoint, prediction of large summer populations should alert operational agencies to intensify monitoring efforts and to be prepared to intensify control. During summer, attempts to control populations by treating adults should be timed to correspond to population peaks, rather than timed to arbitrary schedules. Further research at local levels might establish a means for timing treatments in relation to rainfall. Such a procedure would benefit those operations which unfortunately lack resources for monitoring mosquitoes.

Knowledge of the variation in seasonal populations of *Cx. quinquefasciatus* can be used to make control efforts more efficient. On a yearly time scale, prediction of large summer populations should alert operational agencies to plan accordingly. During the summer season of abundance, attempts at killing adults should be timed to coincide with periods of peak numbers of gravid females. This would have the dual benefit

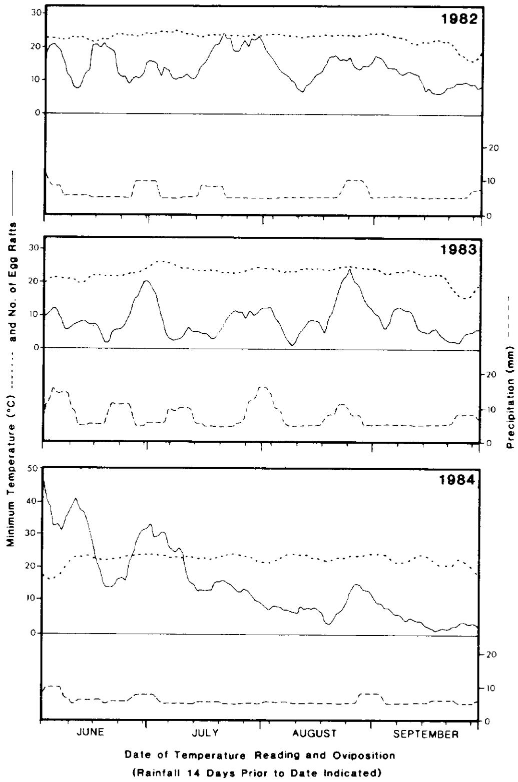

Fig. 2. Summer seven-day moving averages of daily minimum temperature, oviposition by *Culex quinquefasciatus* in 2 foul-water traps, and precipitation. Precipitation is displayed on a scale 14 days prior to oviposition and temperature. Data are for 1982–84 covering June 1–September 30 for temperature and oviposition and May 17–September 16 for rainfall. San Antonio, Texas.

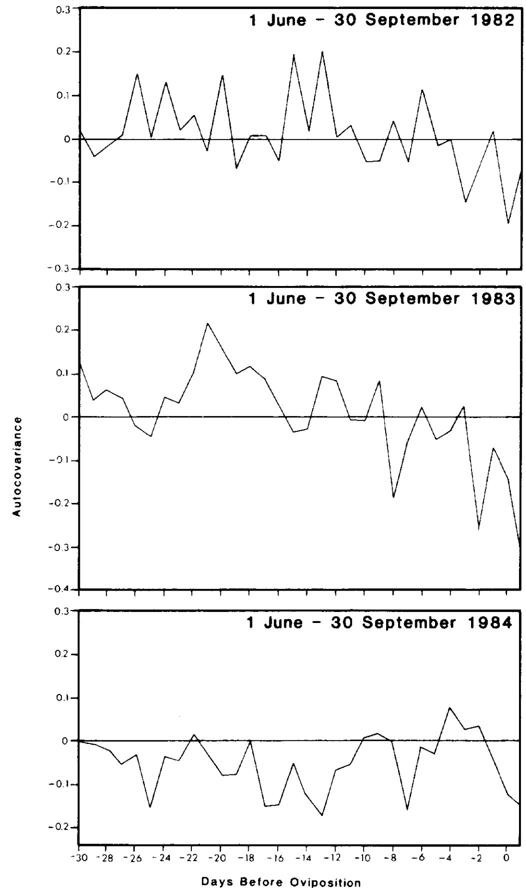

Fig. 3. Autocovariance between rainfall and oviposition by *Culex quinquefasciatus* in 2 foul-water oviposition traps. June 1 and September 30 for each year, 1982–84. San Antonio, Texas.

of affecting the maximum number of mosquitoes per treatment and also reducing that segment of the population most likely to be viremic. Monitoring populations should be done at a local level, preferably at a number of representative sites in the area of concern. Such monitoring might establish local relationships with rainfall and temperature similar to those observed in this study. Once established, these relationships could be used to predict increases in *Cx. quinquefasciatus* populations, allowing time to increase both monitoring and treatment.

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